EPSC Abstracts
Vol. 9, EPSC2014-606-1, 2014
European Planetary Science Congress 2014

Nonlinear Spectral Unmixing of Lunar Analog Materials in the Thermal Infrared Range

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1. Introduction

It has been predicted in [1, 2] that the reflectance spectrum of a mixture of minerals can be described in terms of the Hapke model [3] based on a linear superposition of the spectra of the mineral-specific single-scattering albedo. This approach has been applied to near-infrared (NIR) data e.g. in [4] relying on the analysis of absorption features. Pronounced spectral features are also apparent in the thermal infrared (TIR) range, i.e. the Christiansen feature and the Reststrahlen bands, which may be used to classify different minerals (cf. e.g. [5]). Notably, the TIR range of the spectrum will be measured by the MERTIS instrument [6]. In this study, we apply the Hapke based unmixing method [4] to TIR spectra of mineral powders of 32-63 µm grain size.

2. Sample preparation

For this study, we have used the endmember catalogue of [7] comprised of seven samples from different groups of minerals: augite, diallagite, enstatite, ferrosilite, two labradorites and olivine of 32-63 µm grain size.

2.1 Reflectance measurement

All powders were filled into a circular sample container and flattened. The reflectance was measured using a VERTEX 70v spectrometer and calibrated using a golden plate standard. The incidence angle and emission angle were set to 30° and 15°, respectively, resulting in a phase angle of 45°. To avoid the hydroxyl absorption bands, the 4-17 µm wavelength range is used for the unmixing experiments. It thus covers the whole range of the MERTIS instrument (7-14 µm) [6]. The corresponding endmember spectra are shown in Fig. 1. The range of MERTIS is indicated by the dashed black vertical lines.

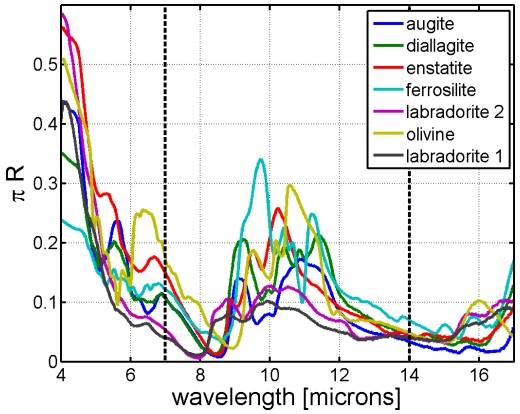

Figure 1: Catalogue of endmember spectra. The dashed vertical lines represent the spectral range of MERTIS [6].

2.2 Preparation of mineral mixtures

In order to prepare accurate mixtures, the corresponding powders were weighed using a high-precision balance and mixed thoroughly by shaking the vessel containing all powders. Table 1 summarises the examined mixtures and weight percent (wt%) fractions, and Fig. 2 shows the corresponding spectra.

3. Non-linear unmixing algorithm

The nonlinear unmixing algorithm from [4, 7] is adapted. Since the number of endmembers in the catalogue is small, an exhaustive search of all possible combinations is applied rather than a genetic algorithm. Additionally, the TIR spectra do not show a continuum. Thus, the spectral parameters from [4] are not used in the error function, such that the spectral unmixing relies on the minimisation of the mean squared difference between the measured and the estimated reflectance spectrum. A separate unmixing is conducted for each wavelength range, i.e. 4-17 µm and 7-14 µm, respectively.

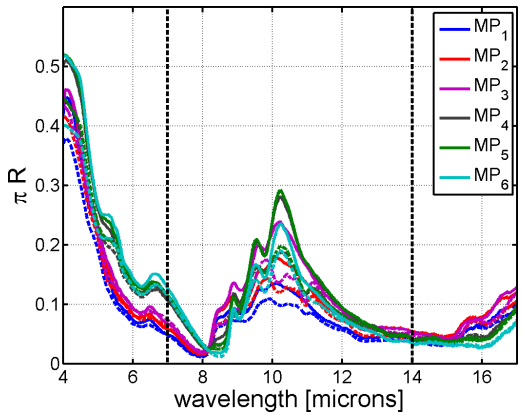

Figure 2: Reflectance spectra of the prepared mixtures and unmixing results. The dashed lines of the same color represent the unmixing results using the full wavelength range. The dashed vertical lines represent the MERTIS range [6].

Table 1: Results of the unmixing algorithm. The dashed lines separate minerals of the same group and thus similar spectra, i.e. pyroxenes vs. plagioclase feldspars.

	Mineral	wt%	4-17 µm	7-14 µm
MP_1	Enstatite	10	1.79	8.85
	Ferrosilite	0	10.14	0.00
	Labradorite 1	90	41.15	67.32
	Labradorite 2	0	45.92	23.83
MP_2	Enstatite	20	0.00	11.00
	Ferrosilite	0	23.98	1.91
	Labradorite 1	80	0.00	55.10
	Labradorite 2	0	76.02	31.99
MP_3	Enstatite	30	0.00	21.66
	Ferrosilite	0	35.50	0.00
	Labradorite 1	70	0.00	21.44
	Labradorite 2	0	64.50	56.90
MP_4	Enstatite	70	56.98	62.01
	Ferrosilite	0	18.40	0.00
	Labradorite 1	30	0.00	0.00
	Labradorite 2	0	24.62	37.99
MP_5	Enstatite	80	68.24	72.44
	Ferrosilite	0	15.44	0.00
	Labradorite 1	20	0.00	0.00
	Labradorite 2	0	16.32	27.56
MP_6	Augite	0	3.04	0.00
	Enstatite	90	91.26	93.22
	Ferrosilite	0	0.00	0.00
	Labradorite 1	10	5.70	0.00
	Labradorite 2	0	0.00	6.78

4. Results and Discussion

The unmixing results for the wavelength ranges 4-17 µm and 7-14 µm, respectively, are shown in Table 1. The detected minerals are grouped by pyroxenes and plagioclase feldspars. The dashed curves in Fig. 2 show the reflectance spectra resulting from the predicted mixtures using the full wavelength range 4-17 µm. All mixtures yield reasonable results and estimated fractions if the individual pyroxene and plagioclase feldspar fractions are combined, respectively. The reflectance spectra of minerals within one group are quite similar, cf. Fig. 1. The spectra of the two labradorites, however, differ strongly in the NIR [7]. A combination of NIR and TIR reflectance spectra may thus be useful to distinguish between minerals of the same group.

4. Conclusion

The obtained spectral unmixing results in the TIR range are promising. It is possible to estimate fractions that are close to the known weight percentage (wt%) if minerals of the same group are combined, i.e. pyroxenes vs. plagioclase feldspars. The distinction between minerals of the same group will be addressed in future work, e.g. by including spectral parameters such as the Christiansen frequency into the unmixing error function, or by a combination of NIR and TIR spectra.

Acknowledgements

We thank Prof. Dr. G. Wörner and Dr. A. Kronz (University of Göttingen) as well as Prof. Dr. P. Walzel and G. Schaldach (TU Dortmund) for their technical support and valuable discussions.

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